A METHOD TO ASSESS THE HYDRAULIC LOADING RATE OF A MARGINAL SOIL

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ABSTRACT

Marginal soils are an unofficial category (of soils) that do not have the desirable hydraulic characteristics of a suitable soil but are not as hydraulically restrictive as an unsuitable soil. Because there is a risk of failure (wastewater standing on the soil surface) when using marginal soils, regulatory officials generally place these soils in the unsuitable category. With the increasing demand for new housing, there is increasing pressure to use marginal soils for wastewater dispersal. The focus of this paper is on a proposed methodology to evaluate soils that have limited hydraulic capacity such to determine an appropriate hydraulic loading rate. This method uses a small-scale drip irrigation system placed on the soil surface in combination with soil moisture sensors to evaluate *in-situ* the rate water can move through the soil profile.

INTRODUCTION

Many decentralized wastewater treatment systems utilize drip dispersal to return reclaimed water back to the environment. In Tennessee, when one of these application systems are proposed, soil scientists determine the suitability of the site by documenting the texture and structure down to at least 21 inches. This morphological method is based on the knowledge that certain combinations of texture and structure would highly restrict the movement of water through the soil profile and these soils would be considered unsuitable. Soils that can move water at an acceptable rate are considered suitable and a loading rate table is used to determine the allowable hydraulic loading rate. At issue is how to evaluate the soils that reside at the dividing line between unsuitable and suitable. These marginal soils will allow water percolation but have morphological properties that raise doubt as to their suitability. There is very little knowledge about how to use marginal soils for reclaimed water dispersal because, when in doubt, the soils are deemed unsuitable.

This article reports on the information gained during the evaluation of a drip-based permeameter to determine the hydraulic conductivity of a soil profile. This activity should not be misconstrued as a return to the historic in-field percolation test that poorly simulated a falling-head permeameter test. This new method applies water over a larger area (36 ft^2) and provides an application rate that can saturate the soil profile to point where water is standing on the soil surface. Once fully saturated, the application rate can be progressively reduced to determine the steady-state rate that matches the ability of the soil profile to move water. The second focus of this effort was to investigate the use of soil moisture sensors to determine the status of the volumetric moisture content as the drip system cycled between doses and during rain events.

MATERIALS AND METHODS

A small drip system was constructed as a 6-ft by 6-ft grid of drip emitters, with laterals spaced 12 inches on-center and emitters spaced 12 inches on-center (36 emitters). This grid was placed directly on the soil surface. Each emitter was rated for 0.55 gallon per hour (gph). With a 36 ft^2

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loading area and one emitter per square foot, the instantaneous loading rate was 0.55 gph per ft^2. Water for the system was stored in a 330-gallon tank, which was refilled as needed from a mobile water tanker.

The control system consisted of a 12 VDC diaphragm pump with a high-pressure shut-off switch, a 5-gallon bladder tank, inline flow meter, pressure gauges, solenoid valves, and a programmable controller/datalogger. The system was powered by a deep-cycle 12 VDC battery and solar panel. An evapotranspiration weather station was used to collect climate data during the experiment.

SOIL MOISTURE SENSORS

Soil moisture measurements were made using Waterscout SM100 sensors by Spectrum Technologies, Inc. (Aurora, IL). These devices measure the dielectric permittivity of the soil, which collates well to the soil moisture content. These sensors return an analog signal that is directly proportional to the volumetric water content. This project did not attempt to calibrate the sensors to the volumetric moisture content. Instead, the millivolt readings were recorded as indicators of the change in the volumetric moisture content. These devices where able to reasonably detect changes in soil moisture during rain events, system dosing, and evapotranspiration. Six sensors were placed within the wetted area (2 at 4" depth, 2 at 8" depth, and 2 at 12" depth). Six additional sensors were placed outside of the wetted area using the same pattern as within the wetted area. Redundant sensors were installed to help account for variability within the sensors and the soils, and because soil moisture sensors tend to fail. As shown in the Results section, at least one of the sensors seemed to go wacko during this investigation.

CLIMATE MEASUREMENTS

A tipping bucket rain gauge was installed at the site. This device measure both rainfall depth and intensity. Each tip of the bucket was equivalent to 0.01-inch of rain. The datalogger recorded the number of tips per hour. An evapotranspiration (ET) weather station was installed to measure high/low temperatures, relative humidity, wind speed/direction, and solar radiation. This project saw higher than normal rainfall and ET was relatively insignificant. As such it is not reported in this document.

SOIL DESCRIPTION

The soil in question is a Bradyville series formed in limestone residuum with a taxonomic class of fine, mixed, semiactive, thermic Typic Hapludalfs. It has horizons of silt loam, silty clay loam, and clay. The structure is weak/moderate subangular blocky. This soil has moderately slow permeability. Chapter 17 (Design Guidelines for Wastewater Dispersal Using Drip Irrigation) of the Tennessee Department of Environment and Conservation (TDEC) Design Criteria for Sewage Works lists this soil as unacceptable for decentralized drip dispersal due to the silty clay texture, with weak blocky structure, located within 20 inches of the surface. This soil qualifies as marginal, it can move water, but at a slow rate.

SYSTEM OPERATION

Data collection began in July 2021. Initially, the system was set to dose for one minute every one-half hour, providing an equivalent application rate of 0.44 gpd/ft^2. After 20 days of operation, the soil surface was saturated within the application area and for five feet down gradient. At that time, the application rate was reduced to a one-minute dose every hour (0.22 gpd/ft^2). After 15 days, the soil was still saturated, but water was not standing on the soil surface. The loading rate was again reduced to a one-minute dose every two hours (0.11 gpd/ft^2). This loading rate was evaluated for two weeks and then it was reduced to a one-minute dose every three hours (0.07 gpd/ft^2). This application rate was continued for two weeks. For the duration of the project, the datalogger recorded soil moisture readings every hour.

RESULTS AND DISCUSSION

There are three recognized soil moisture conditions: Saturated, field condition, and the wilting point. Under saturated conditions, the soil pores are filled with water, and if drainage is possible, the water will move through the profile by gravity. With drainage, the moisture content will decrease until it reaches field condition – the point at which water can no longer drain by gravity because it is being held by the tension forces between the soil particles and the water. Moisture reduction lower than field condition occurs by evaporation and transpiration. A properly chosen (maximum) hydraulic loading rate should maintain the soil moisture in the range of just under saturated conditions to just under field condition. During a dose, the soil moisture content increases above field condition and the excess water moves by gravity. In between doses, the water content equalizes back to field condition. During this time, dissolved contaminants diffuse toward the biofilm and to the surface-active sites located on the soil particles, where much of the renovation process takes place.

Soil moisture sensors were not required to determine when the soil was fully saturated – there was water standing on the surface. However, at the lower application rates, the soil moisture decreased, and the sensors proved to be somewhat useful. Electronic sensing of soil moisture is not an exact science, despite the claims of the manufacturers. Most soil moisture sensors, including the Waterscout SM100, do a fair job of showing trends or changes in soil moisture rather than providing an absolute soil moisture content measurement. As the soil dries (or wets), the trend is shown in the sensor response. However, the sensors do a poor job of sensing differences in soil moisture when the soil is wet, especially between field condition and saturated. Unfortunately, this is the critical range where more information is needed when evaluating the hydraulic conductivity of a marginal soil.

Confounding these results was the rainfall. This location received 13.5 inches of rainfall in the period between July 29, 2021, and September 27, 2021, what should have been the hottest and driest time of the year. Further, this site was used to grow hay, so the ground cover was lush. When it rained, the vegetation allowed for greater infiltration. The 12-inch depth soil moisture sensors provided qualitative information about the amount of rainfall that infiltrated during these events. It is interesting to note that these sensors demonstrated the rapid movement of the infiltrated rainwater during the storm event, and then the rapid movement of water out of the profile after the storm event.

Figure 1 displays the 4-inch depth soil moisture sensor readings. At the higher application rates (0.44 and 0.22 gpd/ft^2), there is little variability in the soil moisture content near the soil surface, the soil stays wet with the excessive water application.

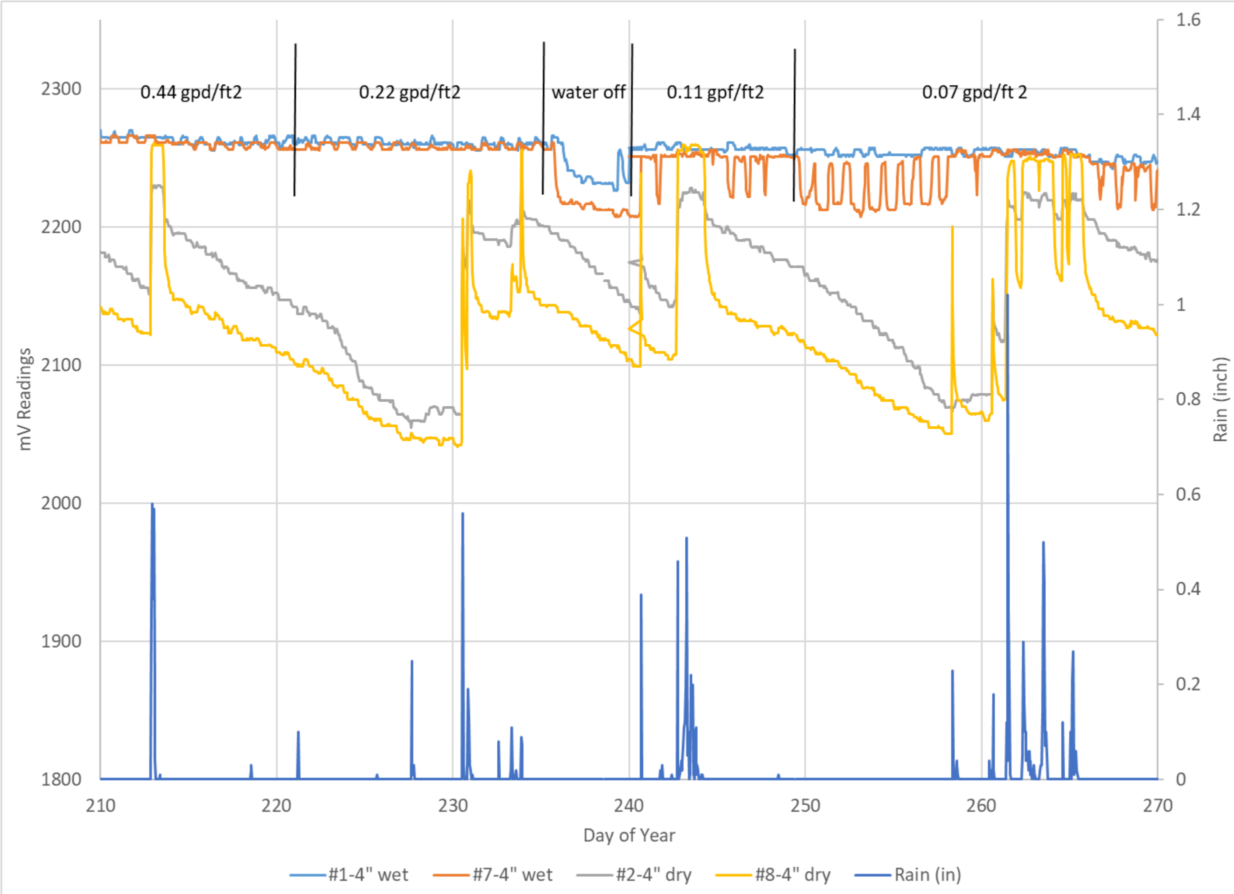

Figure 1 Results from the 4-inch depth soil moisture sensors. The Day of Year is for 2021, DOY 210 is July 29. As shown in this graph, the soil moisture content is represented by the millivolt output of the sensors, higher millivolt readings indicate greater soil moisture content.

When the application rate was reduced (0.11 and 0.07 gpd/ft^2), sensor #7 (orange) produced what appears to be diurnal changes in soil moisture content. This could be due to ET during the day. However, sensor #4 (light blue) does not appear to show the same diurnal response but rather seems to have a slight downward trend as the water application is reduced.

The dark blue vertical lines show the rain events, and it is encouraging to see the soil moisture sensors respond to the extra moisture. Sensors #2 and #8 (gray and yellow, respectively) are outside of the application area. It is interesting to see the soil moisture response to the rain events and to evaportranspiration. They show that water will pass through this soil, and that not all the rainfall soaks into the soil.

Figure 2 displays the 8-inch depth soil moisture sensor readings. This depth represents the soil where drip tubing would likely be installed. Like fig 1, the dry sensors (#4, orange, and #10, gray) demonstrate the rate of moisture loss due to evapotranspiration. The wet sensors (#3, green, and #9, light blue) do trend downward as the application rate is reduced. Rain events do confound some of the data.

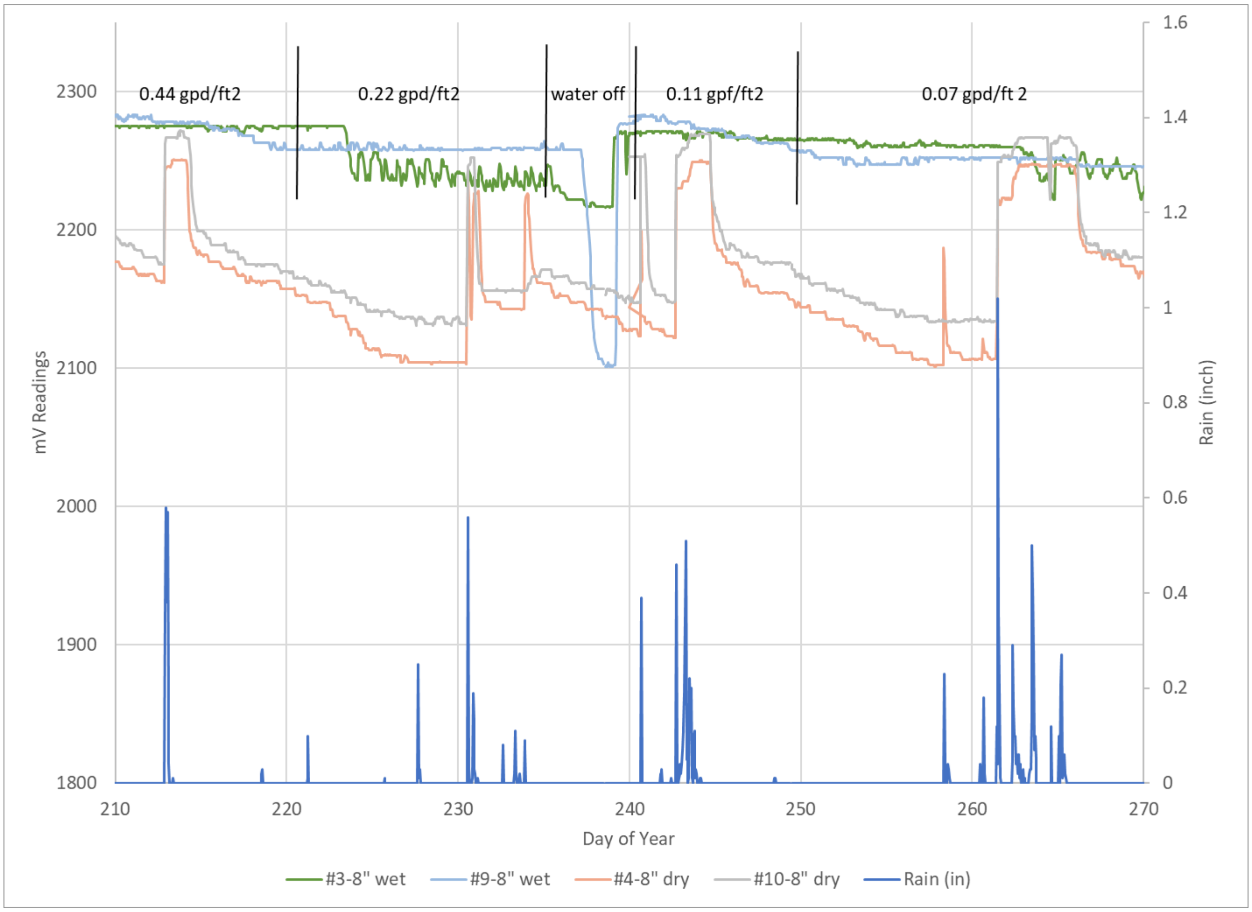

Figure 2. Results from the 8-inch depth soil moisture sensors. The Day of Year is for 2021, DOY 210 is July 29.

Figure 3 displays the 12-inch soil moisture sensor readings. It is interesting to note the dry sensor (#6, orange) readings during and after rain events. The soil wets and then drains rapidly. Sensors in the wet area (#5, green and #11, light blue) do not show lower soil moisture until the application rate is reduced to 0.07 gpd/ft^2.

Effect of Having Emitters on the Soil Surface

The drip system was placed on the soil surface for two reasons: 1) to gain information about the entire soil profile, and 2) the ease of installation. Tennessee (and most jurisdictions) requires the drip system to be installed 6 to 12 inches below the surface. As such, this preliminary investigation may not have represented the soil disturbing effects of the subsurface placement of the drip tubing. Many installations use a vibratory cable-plow to open a narrow slot in the soil and place the tubing. It is not fully understood what effect this soil disturbance has on the movement of water away from the emitters. Because the slot is a continuous fracture, it is thought that it becomes a preferential flow path under saturated conditions. This may be a beneficial effect for distributing water between emitters, which are typically 24 inches apart. The prototype placed an emitter every square foot with the intent to capture the true hydraulic capacity of the soil.

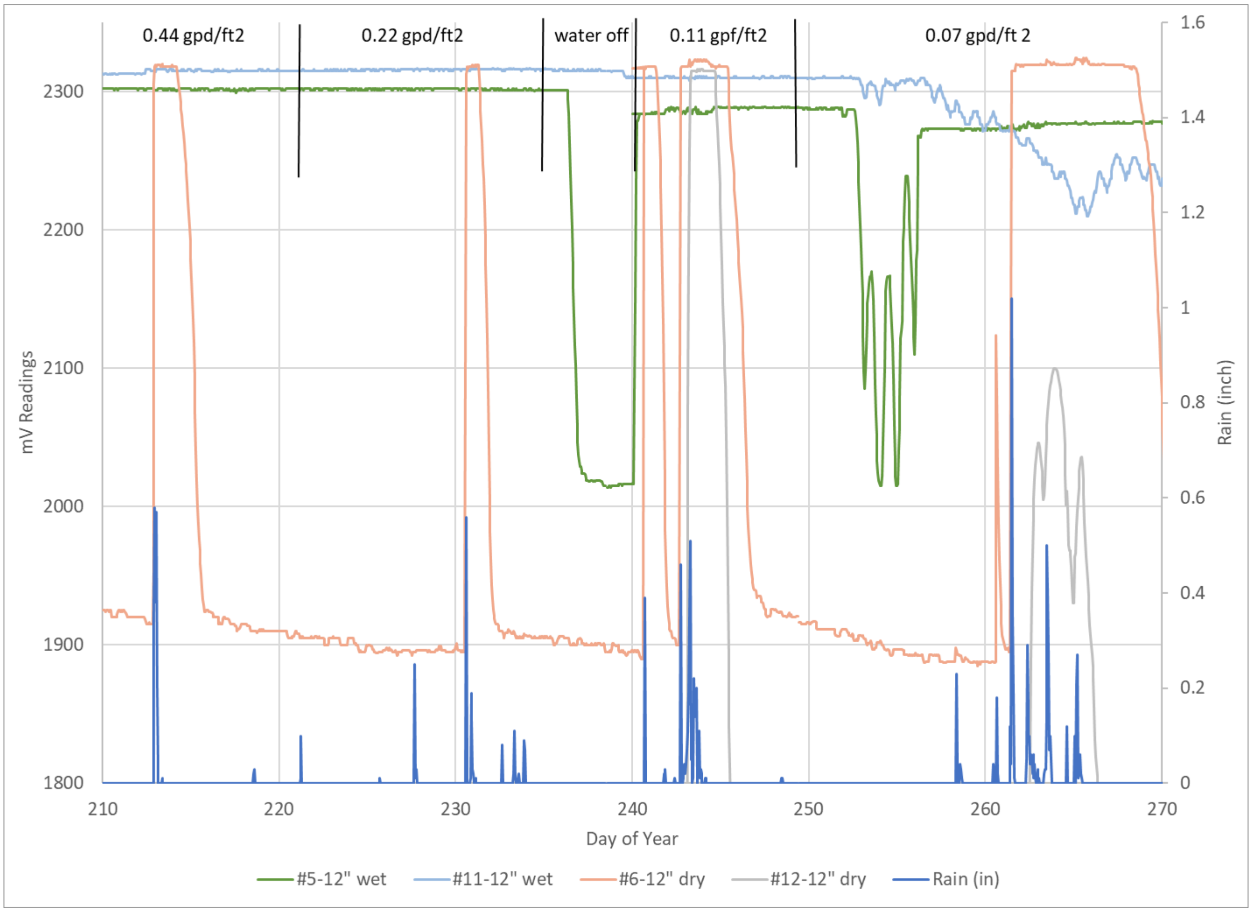

Figure 3. Results from the 12-inch depth soil moisture sensors. The Day of Year is for 2021, DOY 210 is July 29.

CONCLUSIONS

The information provided in this article is the result from one evaluation of a drip-based permeameter prototype. The results are favorable for its continued development. At the 0.07 gpd/ft^2 hydraulic loading rate, the undulation shown in the soil moisture data seems to correspond to the water application and the subsequent movement of water through the profile. The data from this project suggests a maximum hydraulic loading rate of 0.07 gpd/ft^2 for this soil. For decentralized drip dispersal systems, Tennessee uses a wastewater generation value of 300 gallons per day per house, which provides a significant safety factor. As such, the 0.07 gpd/ft^2 will determine the number of homes that can apply water at this location, but because the design-value for generated wastewater is conservative, the actual hydraulic loading rate will be less than the design loading rate.

ACKNOWLEDGMENTS

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